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P. Beiersdorfer, S. B. Utter, G. V. Brown, D. A. Liedahl, C. W. Mauche,
S. M. Kahn, N. S. Brickhouse, A. K. Dupree, R. Mewe, J. S. Kaastra

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P. Beiersdorfer, S. B. Utter, G. V. Brown, D. A. Liedahl, C. W. Mauche
Department of Physics and Space Technology
Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

S. M. Kahn
Department of Physics, Columbia University, New York, NY 10027, USA

N. S. Brickhouse, A. K. Dupree
Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA

R. Mewe, J. S. Kaastra
Space Research of the Netherlands, 3584 CA Utrecht, Netherlands

Using precisely controlled laboratory conditions we have begun to establish a spectral catalogue of the intermediate ionization states of iron, Fe IX – Fe XXIV, in the extreme ultraviolet. The measurements are being performed in support of the development of reliable modeling codes for the analysis of data from the *Extreme Ultraviolet Explorer* and future space astrophysics missions sensitive to extreme ultraviolet radiation. They aim to resolve the controversies surrounding the short-wavelength spectra of stellar coronae. Preliminary measurements showing the wealth of iron lines in the 50–120 Å region are presented.

1. Introduction

With the launch of the *Extreme Ultraviolet Explorer* (*EUVE*) in 1992, the extreme ultraviolet spectral region from 70 to 400 Å has been opened to stellar astrophysicists for high-resolution exploration. *EUVE* observations have provided superb spectra of stellar coronae. These are used to derive densities, abundances, and, very importantly, explicit information on the temperature structure of stellar coronae not provided by any other means (Dupree *et al.* 1993, Brown 1994, Vedder *et al.* 1994, Mewe *et al.* 1995, Schrijver *et al.* 1995). The tremendous diagnostic opportunities are the result of the wealth of emission lines that mark the extreme ultraviolet spectral region. Apart from several important lines produced by carbon, nitrogen, oxygen, and neon, the extreme ultraviolet region contains rich line emission from virtually all charge states of iron. In particular, the region contains the M-shell spectra, i.e., transitions of the type 3ℓ-$n\ell'$, of ionization states Fe IX – Fe XVII, and the L-shell spectra, i.e., transitions of the type $2s$-$2p$, of the ionization states Fe XVIII – Fe XXIV. These provide line diagnostics for a broad temperature range: the transition region ($T \leq 5 \times 10^5$ K), the "quiet" corona ($T \approx 1 - 2 \times 10^6$ K; e.g. Fe IX – Fe XII), active regions ($T \approx 2 - 5 \times 10^6$ K; e.g. Fe XIV – Fe XX), and flares ($T \geq 10^7$ K; e.g. Fe XXI – Fe XXIV).

The analysis of high-resolution spectra from *EUVE* is, however, not without problems. In fact, the spectra, especially those obtained in the short wavelength (SW) band, 70–180 Å, cannot be fitted properly without making controversial assumptions. The reason is that the intensity of the observed lines and that of the continuum level even of well behaved stars, such as the spectrum of the G-K binary α Cen cannot be fitted in a consistent manner. For example, to obtain a fit with the widely used spectral analysis computer code SPEX (Kaastra *et al.* 1996) required the unphysical assumption of a high-temperature tail on the differential emission measure (DEM). By making the assumptions that the metal abundances are well below (solar) photospheric values this problem can be resolved. However, this would imply a coronal abundance effect that is opposite to what is seen in the Sun. Another, yet more controversial resolution to the problem was offered by Schrijver, van den Oord, & Mewe (1994) and Mewe *et al.* (1995) who suggested that resonance scattering of the emission lines may be the cause for the low line-to-continuum ratio. A final scenario for fitting the spectra was offered by Jordan (1996), Schmitt, Drake, & Stern (1996) and Drake, Laming, & Widing (1997), who argue that what appears to be a high continuum is the result of many lines missing in the spectral fitting model. They argue that including such missing lines will lower the continuum emission necessary to fit the SW spectrum and will provide a good fit without invoking opacity effects, high-temperature tails on the differential emission measure, or metal abundance deficiencies.

To address the controversies surrounding the interpretation of the *EUVE* spectra we have recently begun a systematic laboratory investigation to measure the emission lines from the intermediate charge states of iron between Fe IX and Fe XXIV in the extreme ultraviolet regime. First results are presented below.

2. Spectroscopic Facility and First Results

The measurements are being carried out using the spectroscopic capabilities at the Livermore Electron Beam Ion Trap facility. The EBIT is a modified electron beam ion source built to study the interaction of highly charged ions with an electron beam by looking directly into the trap. The device is described by Levine *et al.* (1988) and the spectroscopic capabilities are described by Beiersdorfer *et al.* (1993,1994). The electron density for the present experiments is about 5×10^{11} cm^{-3}, i.e., comparable to the density found in stellar coronae. By setting the electron beam to a particular energy it is possible to select the charge state of interest for spectroscopic study.

Spectra are acquired with a flat-field spectrometer utilizing a variable line spacing grating (average 1200 ℓ/mm) with a focal distance of about 27 cm. The spectrometer utilizes a thinned, back-illuminated, LN_2-cooled CCD camera (1024 x 1024 pixels) for the detection of the dispersed photons. We use the CCD in the charge integration mode.

We have begun to make measurements of iron emission lines by setting the spectrometer to the short wavelength portion of the spectral region of interest. A typical spectrum covering the region between 50 and 120 Å is shown in Fig. 1. The spectrum was obtained by setting the electron beam energy to 280 eV, i.e., an energy where iron charge states no higher than Fe XI are produced. For comparison, we show in Fig. 2 a spectrum recorded at a beam energy of 330 eV. At this energy iron charge states no higher than Fe XIII are produced.

The two spectra in Figs. 1 and 2 are clearly different. By systematically recording

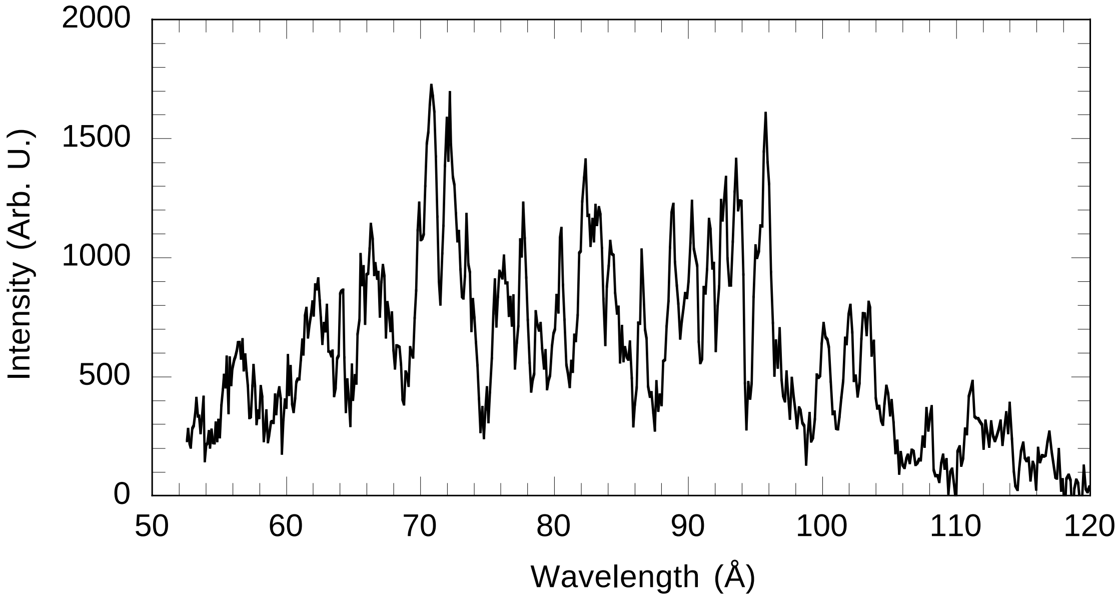

Figure 1: Line emission spectrum of iron in the extreme ultraviolet measured at the Livermore spectroscopy facility. The electron beam energy was 280 eV. Only charge states as high as Fe XI were produced and excited.

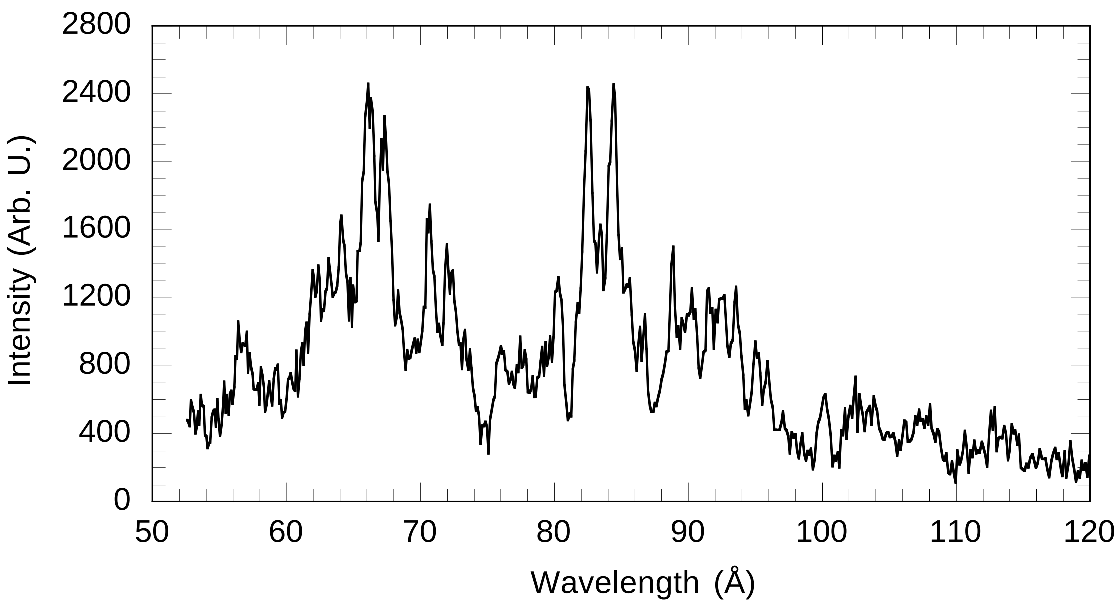

Figure 2: Line emission spectrum of iron in the extreme ultraviolet measured at the Livermore spectroscopy facility. The electron beam energy was 330 eV. Only charge states as high as Fe XIII were produced and excited.

spectra at different energies we are able to identify which lines are produced by which charge state of iron. This procedure is necessary because essentially none of the lines shown in the Figs. 1 and 2 have been observed and identified in previous measurements.

3. Conclusion

Even though our measurements have just begun, they already show that the extreme ultraviolet wavelength band indeed contains numerous unidentified emission lines. Figures 1,2 show rich spectra comprised of many blended lines that almost look like continuum emission. This provides evidence for the contention that missing lines could be the reason why it is so difficult to fit *EUVE* SW spectra. Indeed, comparing these with an *EUVE* SW spectrum from SS Cygni (Mauche, Raymond, & Mattei 1995) corrected for interstellar absorption show striking similarities. This suggests that the laboratory measurements might truly play a key role in understanding the astrophysical data. Spectra in the 200-Å region important for cool stars will be studied soon as well.

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